NASA Stennis Space Center Test Technology Branch Activities

3rd International Hydrogen Peroxide Propulsion Conference
November 13 - 15, 2000

Wanda M. Solano
National Aeronautics and Space Administration
John C. Stennis Space Center
Code VA34 Building 8306
Stennis Space Center, MS 39529-6000
228-688-2655

Keywords: NASA, Stennis Space Center, Test Technology, Plume, Radiometry, Acoustic, Data Acquisition, Sensors

Abstract

This paper provides a short history of NASA Stennis Space Center's Test Technology Laboratory and briefly describes the variety of engine test technology activities and developmental project initiatives. Theoretical rocket exhaust plume modeling, acoustic monitoring and analysis, hand held fire imaging, heat flux radiometry, thermal imaging and exhaust plume spectroscopy are all examples of current and past test activities that are briefly described. In addition, recent efforts and visions focused on accommodating second, third and fourth generation flight vehicle engine test requirements are discussed.

Introduction

Stennis Space Center, in Hancock County, Mississippi, is NASA's lead center for rocket propulsion testing. The Test Technology Branch, in the Propulsion Test Directorate, facilitates rocket engine testing in areas not traditionally supported by the Operations Division or Design and Analysis Branch. Recent and past activities include engine performance exhaust plume spectroscopy, hydrogen fire detection, imaging and smoke/fog penetration, vehicle design and facility protection analysis using heat flux radiometry, thermal imaging to identify hardware degradation, acoustic monitoring and analysis for sound pressure level predictions, and theoretical rocket exhaust plume prediction modeling. In addition, Test Technology Branch engineers, working together with in-house contractors and university faculty, engage in developmental efforts intended to address and resolve facility sensor, instrumentation, data acquisition and control challenges as they arise. Examples of the Test Technology Branch's current developmental projects include investigations into non-intrusive flow measurement, automatic signal conditioning and data acquisition, intelligent health monitoring and diagnostics, advanced fiber optic sensor technologies, flow-induced vibration analysis techniques, next generation accelerometers and implementation of a plume experimentation test-bed. Test Technology is also preparing for accommodating next generation flight vehicle engine test requirements with future research and development projects that may include alternate thrust measurement techniques, real time computer cluster signal processing, emission system design upgrades, and atmospheric transmission modeling to name a few.

Brief History

In October 1961 NASA announced its decision to establish a national rocket test site in Hancock County, Mississippi [1]. The test facility resides on 13,500 acres of land with a sound buffer close to 125,000 acres. The site was officially named Mississippi Test Operations (MTO). MTO was designated as the Mississippi Test Facility (MTF) in 1965 where in the following year the first Saturn V rocket booster (S-II-T) was tested. In 1970, NASA announced that the Earth Resources Laboratory (ERL) will locate at MTF. The center was again re-named in 1974 to the National Space Technology Laboratories (NSTL) and one year later conducted the first Space Shuttle Main Engine (SSME) test. The Remote Sensing Branch of ERL began the SSME Vehicle Health Management (VHM). NSTL was re-named John C. Stennis Space Center by executive order of President Ronal Reagan in 1988 and designated the Center of Excellence for Large Propulsion System Testing in 1991. The Remote Sensing Brach was relocated under the newly established Propulsion Test Directorate. The Remote Sensing Branch was later reorganized into the Science and Technology Laboratory (STL) and continued work on the Diagnostic Test Bed Facility (DTF) to provide a test bed for development of rocket engine exhaust plume diagnostics methodologies and instrumentation [2]. The Test Technology Branch grew out of STL and is now housed in building 8306. Dr. Bill St. Cyr is Branch Chief.

Survey of Current and Past Activities

- Exhaust Plume Spectroscopy

  Custom spectral analysis emission spectroscopy systems have been developed to detect minute levels of metallic contaminants indicative of abnormal engine wear. Optical Multichannel Analyzer (OMA) based systems have been used since 1989 to acquire Space Shuttle Main Engine (SSME) exhaust plume spectral data [2]. Engine performance conditions are correlated to specific engine components and materials in the hot-gas path that erode into the exhaust plume. Two optical channel analyzers are used with one for atomic metals and the other for molecular compounds. With emission spectroscopic techniques the collection optics is focused at the mach diamond disk as shown in Figure 1, where supersonic flow transitions to subsonic flow.

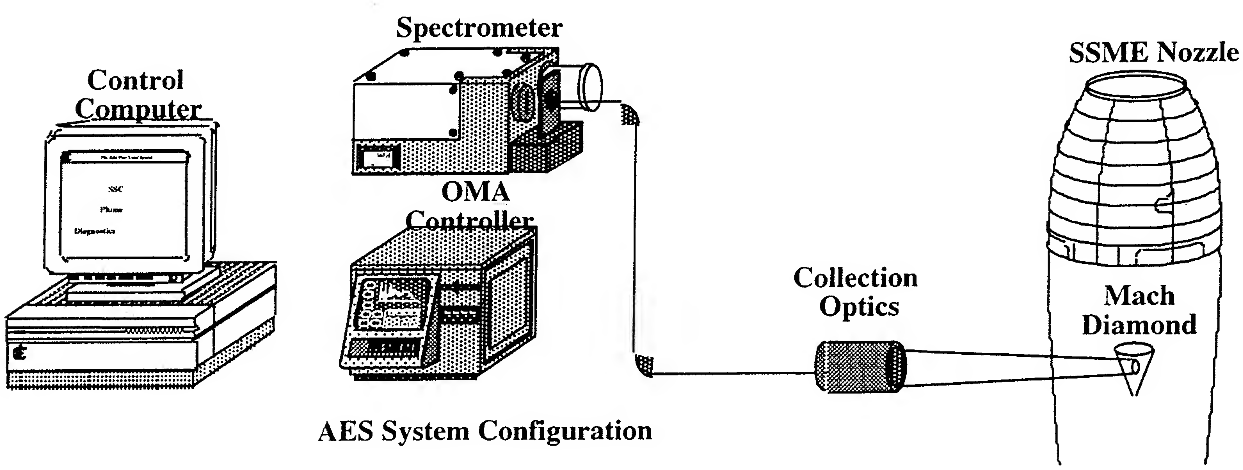


Figure 1

An example of a typical plume diagnostic waveform is shown in Figure 2, where chromium emission intensity is shown over test time for three separate tests.

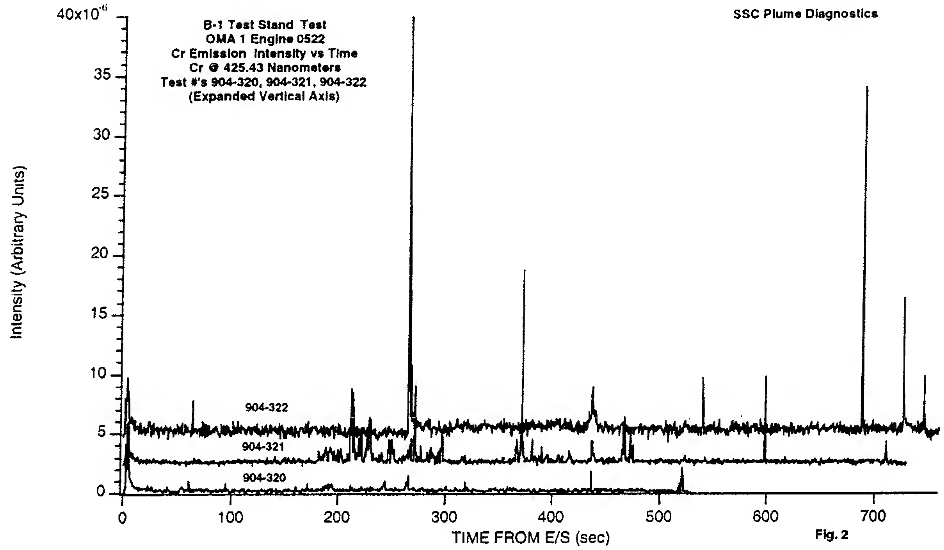


Figure 2

Figure 3 shows the instrumentation used for absorption spectroscopy. Absorption spectroscopy is also routinely used for SSME engine testing when testing with a diffuser, where a mach diamond disk is not present. The limitation on absorption spectroscopy is that the element to be measured must be incorporated into the hollow cathode lamp prior to taking the test and only the selected wavelength can be detected.

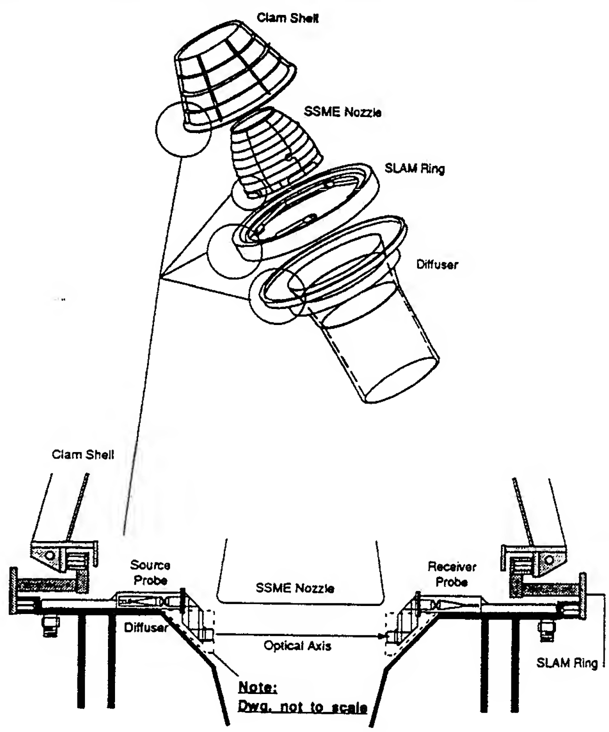


Figure 3

- Hydrogen Fire Detection, Imaging and Smoke/Fog Penetration

Liquid hydrogen flames are virtually invisible in daylight because of the cryogenics clean-burning chemical makeup. A hydrogen fire plural wavelength flame detector was developed in collaboration with Kennedy Space Center (KSC) that discriminates between direct and reflected radiation. The device, shown in Figure 4, detects fires in the background of other emitted radiation. These instruments have been installed and are in use at KSC.

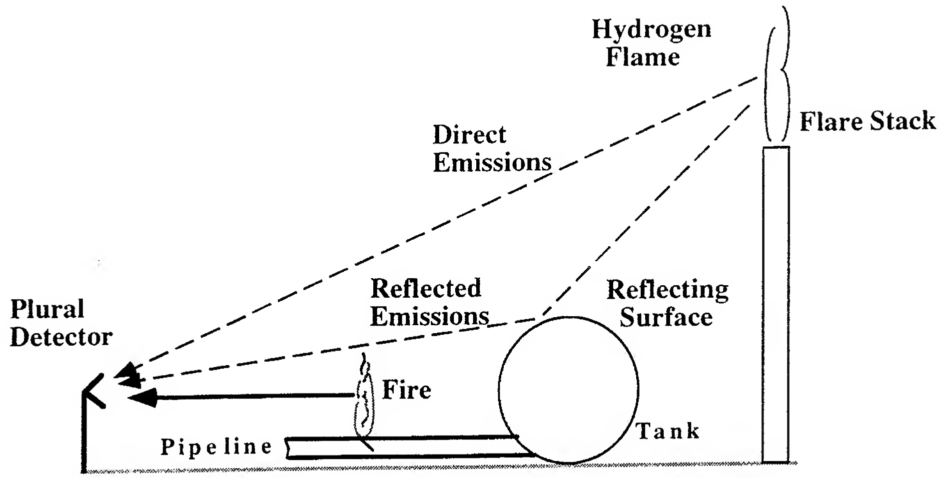
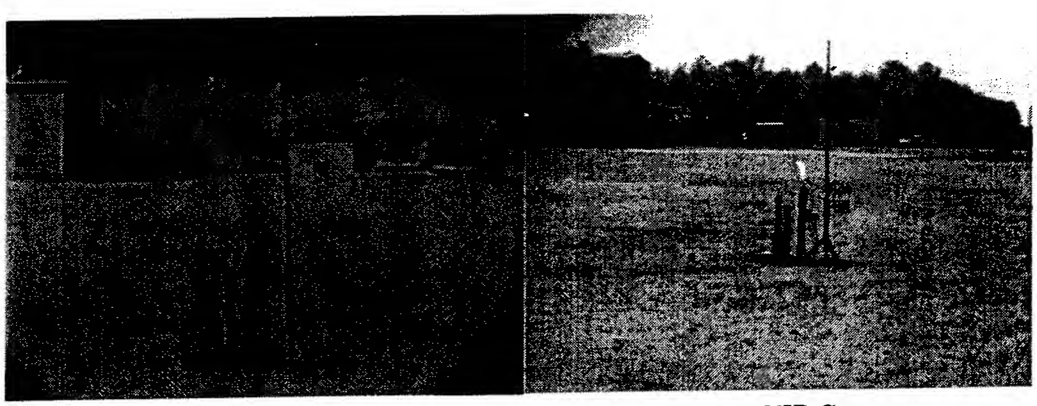


Figure 4

For low-cost and mobile fire searching, the 1991 National Fire Protection Association (NFPA) handbook recommends throwing dirt into the suspect area or probing the area with a corn straw broom [3]. The Stennis Space Center Fire Department has replaced NFPA methods of hydrogen flame detection with a hand-held fire imager. The imager uses black-and-white surveillance-type cameras and operates at near-infrared (NIR) wavelengths of light, similar to those used by a television remote control. A comparison of a visual image of a hydrogen flame is compared in Figure 5 where the broadband IR camera image is shown on the left and the bandpass NIR camera image is shown on the right. The image is clearly visible with the NIR camera. The instrument can distinguish between the background images and the fire. Used like binoculars, the device has the capability to image an 8-inch flame from 50-feet away.



Broadband IR Camera **Bandpass NIR Camera**

Figure 5

A compact helmet-mounted imaging system coupled with heads-up display (HUD), as shown in Figure 6, has been conceptualized and is in development at Stennis Space Center (SSC) [4].

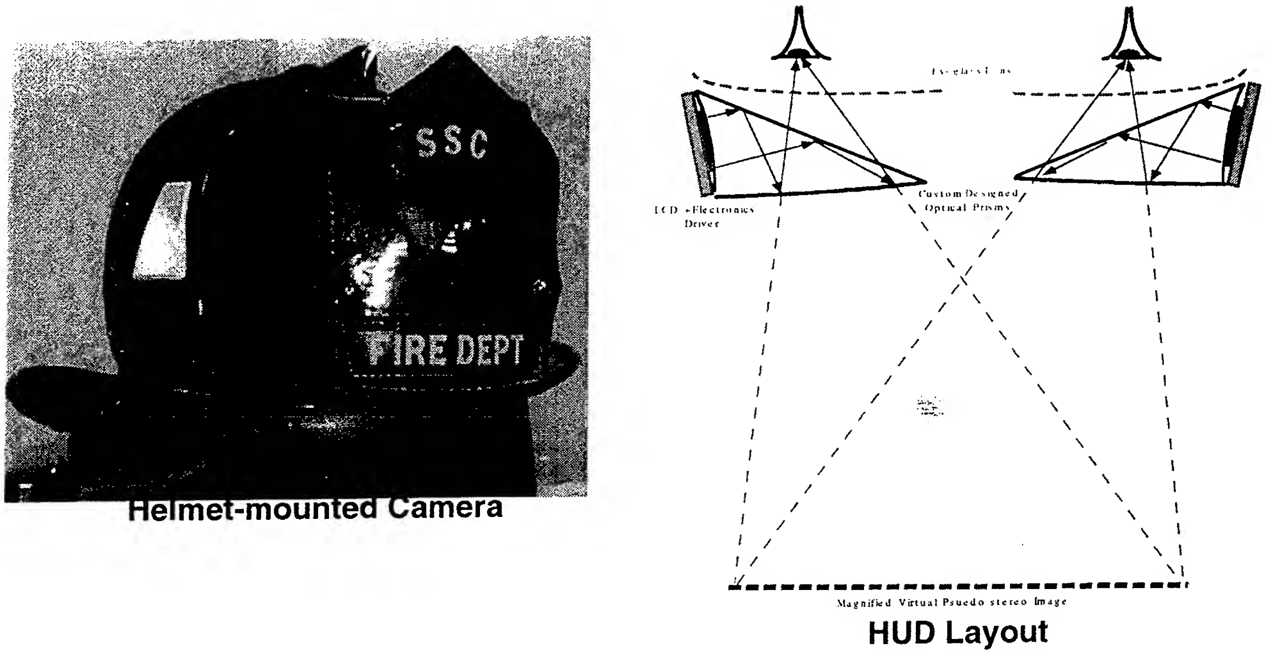
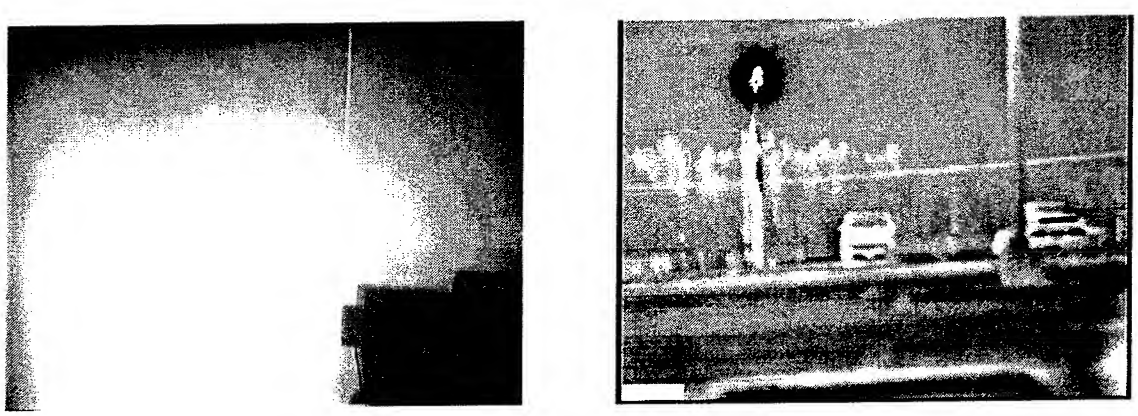


Figure 6

The development was specifically designed to provide firefighters and emergency response personnel with the ability to work more efficiently in adverse conditions of heavy smoke, fog and darkness. The camera system has the capability to penetrate darkness and see through smoke and fog without difficulty. A normal view of a flare stack is shown in Figure 7, where light smoke completely diminishes the view, while the thermal camera view increases visibility considerably. Coupled with the HUD, a user can see the video information from the camera super-imposed within the field of view (FOV). The system is essentially hands free, thereby allowing personnel to be engaged fully with necessary activities. The system does not need any adjustments by the user.



Normal View **Thermal Camera**

Figure 7

- Vehicle Design Support Using Heat Flux Radiometry

  Heat flux radiometry measurements have been used to define facility areas that require protection from high heat loads and help to mitigate damage to test articles. For example, measurement data has been used to validate CFD prediction computer codes developed to identify areas of thermal load on the aft of the X-33 Advanced Technology Demonstrator flight vehicle. Figure 8a is a view of radiometers that were mounted in the areas around the engine that corresponded to specific vehicle aft locations. Also shown in Figure 8b is a sample of test data that shows radiation rates for several radiometers over test time, the associated chamber pressure and a comparison to the predicted radiation rate.

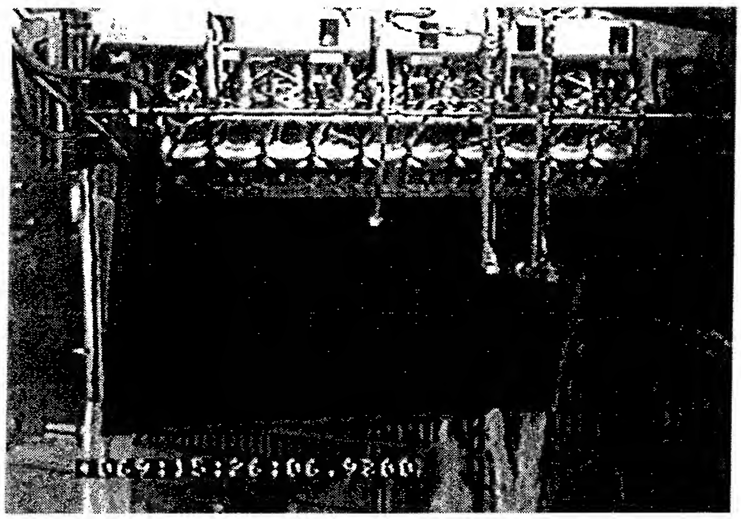


Figure 8a

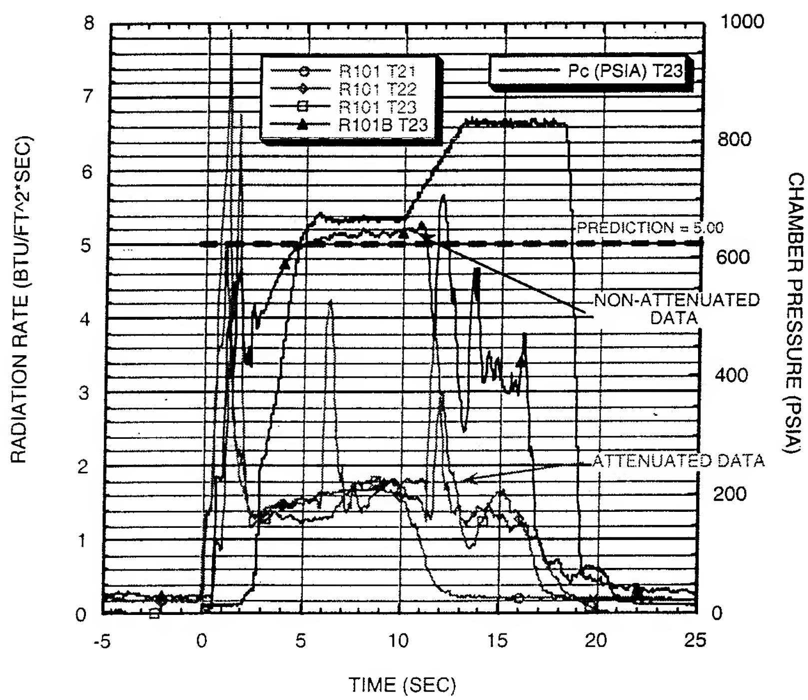


Figure 8b

- Thermal Imaging

    Thermal imaging is used for engine and engine plume diagnostics. For engine thermal imaging, two thermal imagers, with sensitivities from ambient to several thousand degrees are used to map 360 degrees of the test article to show hot spots and other engine thermal indications. The images are pseudo color or gray scale and available as integrated area temperatures or point measurements. For engine plume thermal imaging, ultra-violet (UV) and near-infrared (NIR) cameras are used. These measurements are used to map plume boundaries, visualize plume internal flow-fields and indicate combustion stability and other plume anomalies. An example is shown in figure 9, where thermal IR imaging (8-14 micron) of rocket exhaust plumes is used to show abnormal degradation of injector material. Metal material in the gas is visible due to increased emissivity.

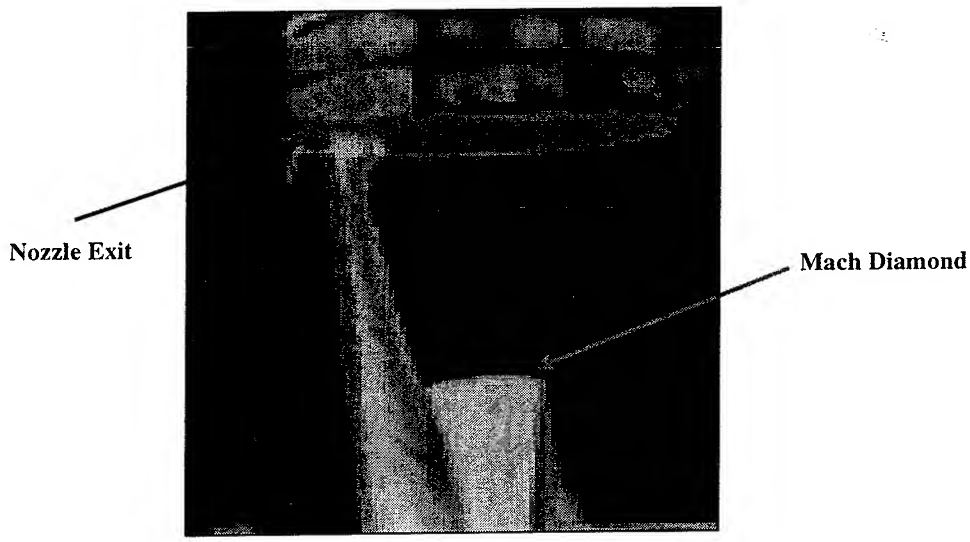


Figure 9

- Acoustic Monitoring and Analysis

    Acoustic monitoring and analysis capabilities include facility and test article mid-field acoustic monitoring and free field measurement of test acoustic signature and sound pressure levels. The acoustic levels generated by large rocket propulsion systems can have significant impact not only on the flight vehicle, but also on ground test facilities and personnel. Stennis Space Center has undertaken an extensive program to monitor and characterize the acoustic signatures of engines undergoing ground test and to support the development and validation of predictive models for acoustic emissions. A suite of instrumentation, including precision microphones, overpressure sensors, strain gages and signal conditioning and recording equipment is available to support both near and far field acoustic measurements. Data reduction and analysis programs have been developed that allow detailed analysis of the recorded acoustic data, examples of which are shown in Figure 10a & 10b. Data has been utilized to predict sound level impact on facility structures, shown in Figure 10c and for vehicle design.

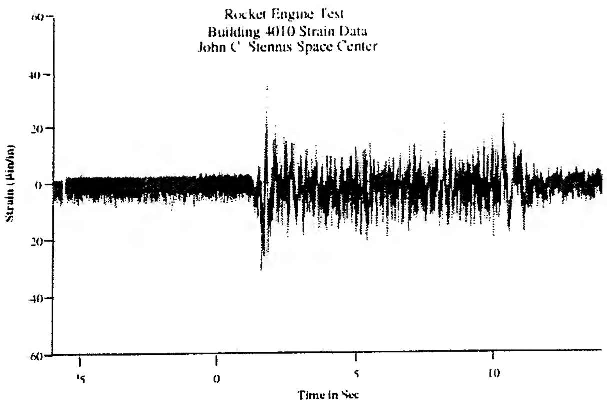


Figure 10a

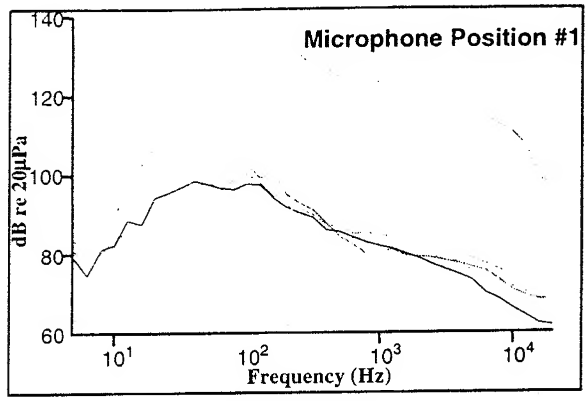


Figure 10b

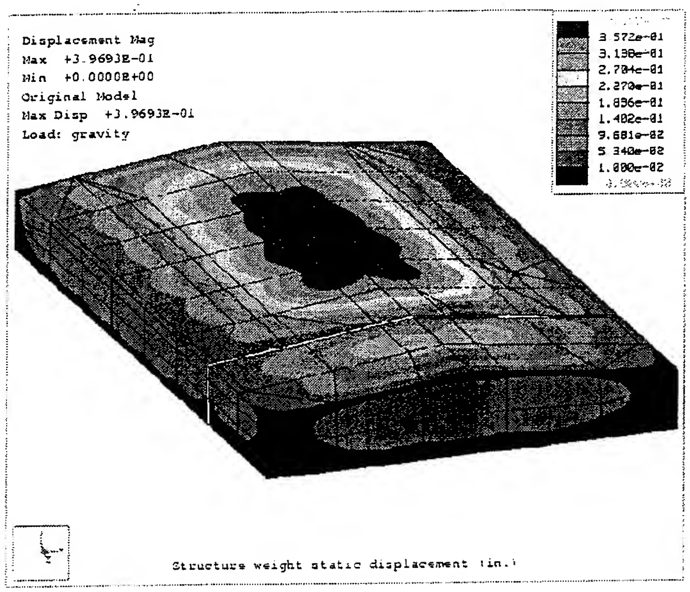


Figure 10c

- Theoretical Rocket Exhaust Plume Modeling

  Rocket plumes have been analyzed using computational fluid dynamic (CFD) techniques. The results have been used to design custom flame deflectors, obtain plume-induced environment predictions, and predict spectral characteristics for engine health monitoring. Figure 11 shows an example of how the plume model was generated to determine where the mach diamond disk was located in order to position spectroscopic optical collection equipment. Also shown is a model of the motor plume impingement on the tarmac and it's predicted heating.

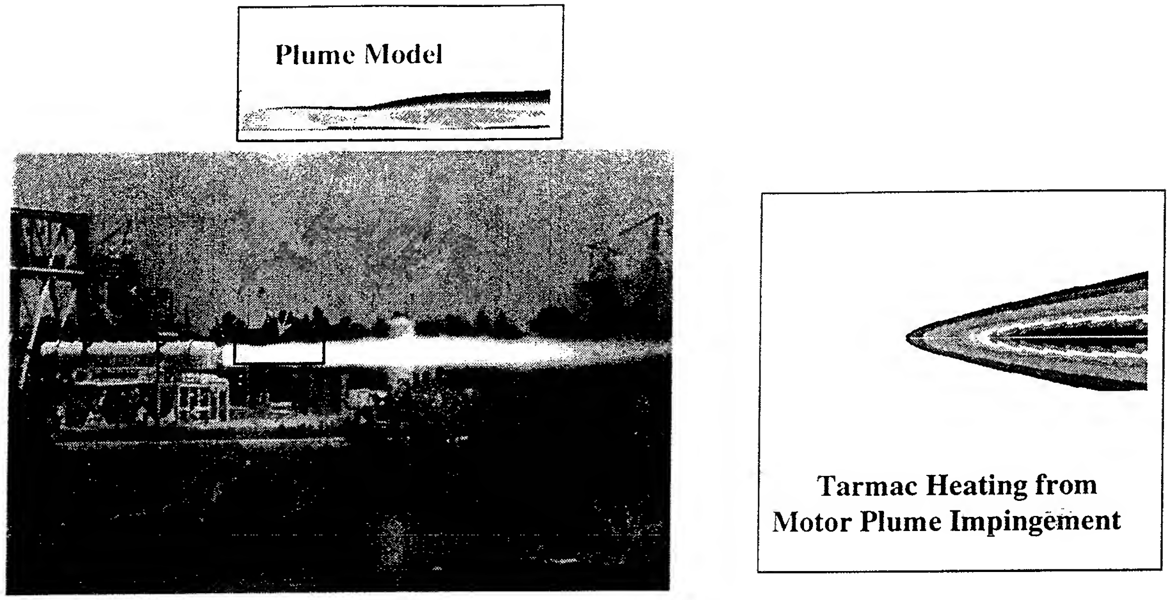


Figure 11

- SSC Beowulf Cluster and Computational Fluid Dynamics (CFD) Applications
  A Beowulf cluster has been configured at SSC and shown in Figure 12. The cluster has been used in a variety of applications:
  - Support plume-induced environment studies to ensure proper flame deflector and structural operation.
  - Determine optimum locations for sensors that measure flow properties of rocket exhaust plumes.
  - Ensure that NASA/SSC meets EPA guidelines by estimating the amounts of pollutants released into the atmosphere by rocket engine tests.

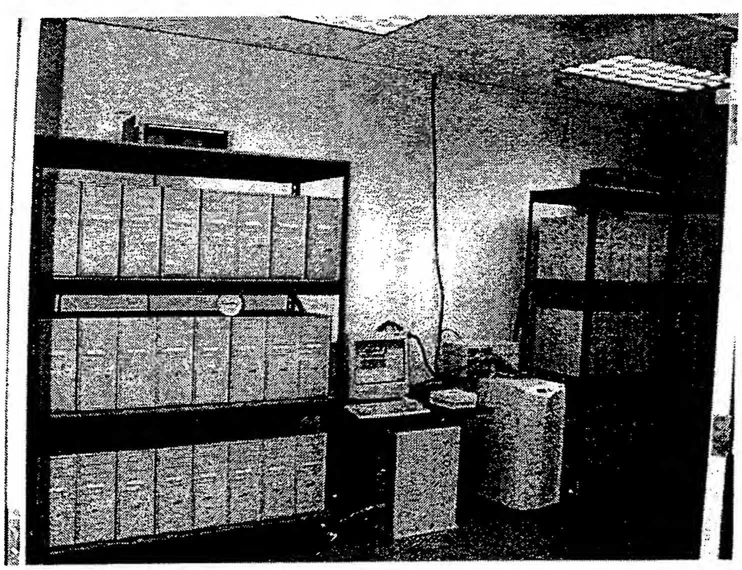


Figure 12

The SSC Beowulf Cluster has the following characteristics: 48 dual Pentium II CPUs, 400 MHz, Red Hat LINUX 6.0, 19.6GB, Memory, 370 GB Hard Disk Space, 72 ports of 10Mbps, full duplex network connection.

Examples of Current Development Efforts

- Non-Intrusive Flow Measurement

  Fluid flow measurements are an essential part of the engine testing and performance evaluations. Non- intrusive flow measurement technology could provide improved and more accurate instrumentation for SSC test stands application. A comprehensive study of the flow measurement requirements and the current methodology utilized at the SSC test stands is being conducted to select the promising technologies for further development for application to the SSC engine testing environment.

- Automatic Signal Conditioning and Data Acquisition

  The propulsion test environment shares many features in common with the data acquisition requirements of industries including manufacturing and process control. Of continuing interest are those techniques that can help reduce the personnel costs needed to reconfigure systems to fix problems and meet new requirements. Another critical need is improvements in the quality and reliability of measurements—i.e., monitoring the health of the data acquisition system. The universal signal conditioning amplifier (USCA) developed at Kennedy Space Center (KSC) [6] is being evaluated for adaptation to the SSC testing infrastructure. The primary focus is to determine system design modifications that would provide enhanced flexibility, reduced costs, and include health monitoring. Results should be of interest to a variety of data acquisition users.

- Intelligent Health Monitoring and Diagnostics System

  The IHMDS is based on two key elements: A modeling method to instantiate each sensor as a highly autonomous sensor (HAS), and a structure suitable for a network of controllers, processes, and sensors to implement sensor fusion at a high-qualitative level [7]. This is illustrated in Figure 13.

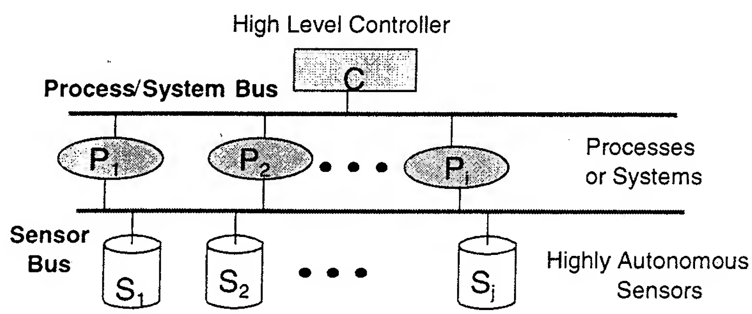


Figure 13

The IHMDS focuses on modeling sensors as intelligent (highly autonomous) agents that operate as elements of a distributed network of sensors, processes, and controllers. A

modeling method will be used to embed into any sensor the ability to extract qualitative behaviors from the data it reads. Hence, each sensor will provide a qualitative description in-time of the behaviors experienced by the parameter it monitors (e.g. tank pressure step change). Even though there are many commercial trending software packages, none is capable of describing trends as qualitative behaviors where the key features are shapes of a signal, regardless of the values. The ability to extract these qualitative behaviors is a very powerful tool for monitoring and diagnosis since it mimics how expert operators perform these tasks. With all sensors in a system modeled as highly autonomous, a fusion method at a high-qualitative level will be implemented to perform monitoring and diagnostics. A figurative view of this is provided in Figure 14.

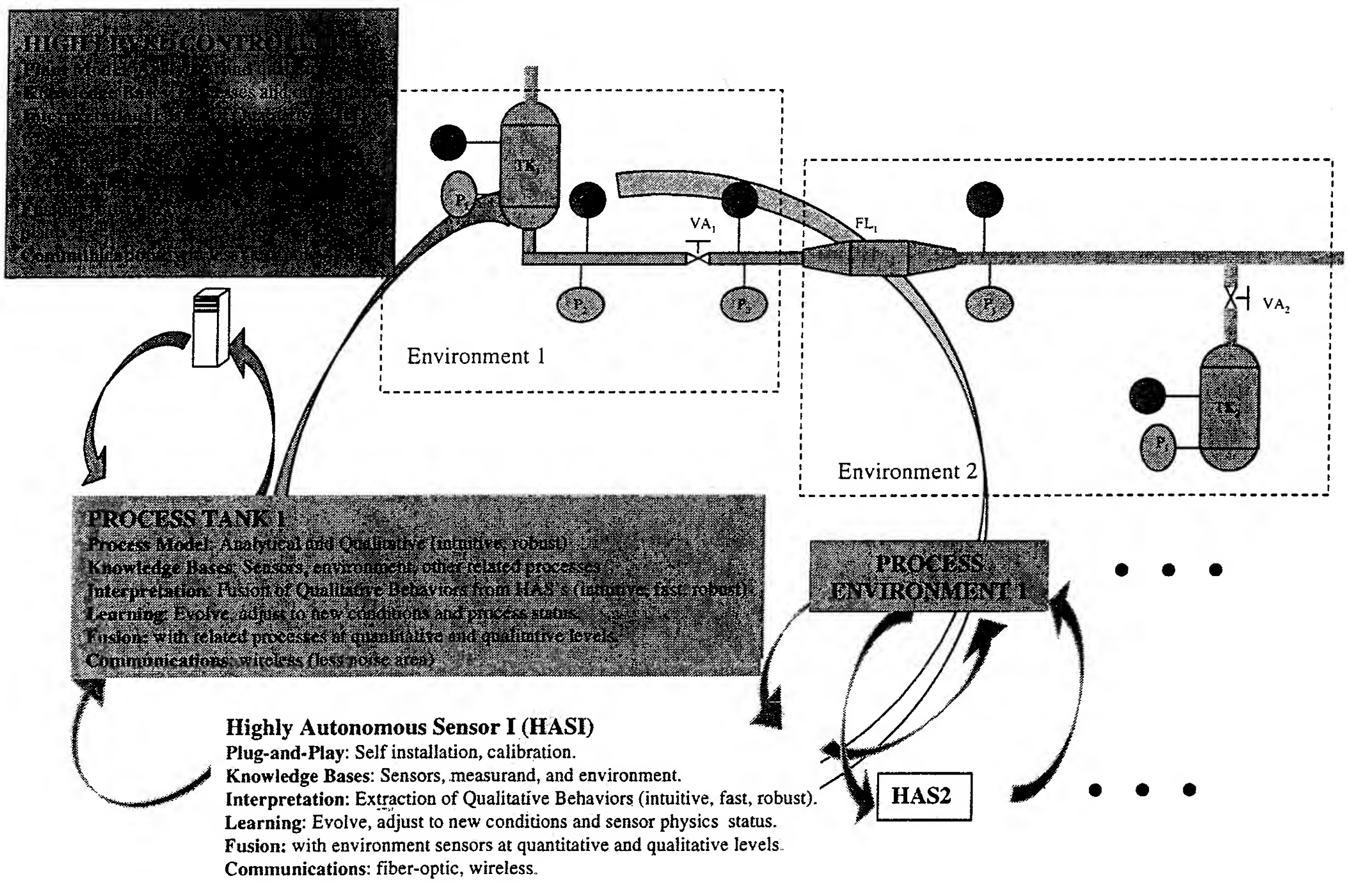


Figure 14

- Fiber Optic Sensors

Fiber optic sensor technology offers the possibility of low cost, multi point measurement of many parameters important in propulsion system ground testing and flight environments. These include pressure, temperature, vibration, stress, etc. Existing sensor designs are being evaluated for their applicability to propulsion system testing / flight applications and the designs modified and tested as needed to meet application specific requirements. For example, a distributed fiber optic sensor system is being considered for development for propellant tank level measurements.

- Flow-Induced Vibration Analysis Capability

  A large amount of propellants at high pressures are required for the rocket engine testing. Propellant transfer is done by means of the piping systems. These piping structures are subject to flow-induced vibration due to turbulence in the flow or, sometimes, due to resonance with some periodicity in the flow, which may itself arise by fluid-structure interaction. Also, the structure may be subject to fluidelastic instabilities of different types. Fairly significant vibrations have been observed at the test stands during propellant transfers on some occasions. Prevention of these occurrences requires a better understanding of the problem by means of analytical tools. Analytical tools/insights are being developed to identify likely situations where flow-induced vibrations are going to be a significant problem.

- Next Generation Accelerometers

  Sensors used for data acquisition and control fall loosely into two categories, facility or test article. Facility sensors refer to those used in conjunction with the propellant delivery and thrust measurement systems. These sensors are generally considered to be an integral part of the "test stand" data acquisition and control system. Test article sensors refer to those used to monitor the behavior and performance of the engine or device under test. These sensors are configured into the resident data acquisition and control system as needed and required for each particular engine test program.

  Accelerometer and vibration measurements are often utilized as part of the rocket propulsion testing system and can fall into either the facility or test article category mentioned previously. They are used in a wide variety of applications such as in support of building structural response studies, flow induced vibration RMS measurements, turbo pump RPM measurements and other rocket engine testing related applications. In order to accommodate the need for a versatile, quickly and easily installed and configurable acceleration and vibration measurement device a developmental project was undertaken to determine the feasibility of producing a low-cost low-power wireless MEMS-based accelerometer system (MEMBAS). The preliminary architecture is shown in Figure 15 [8].

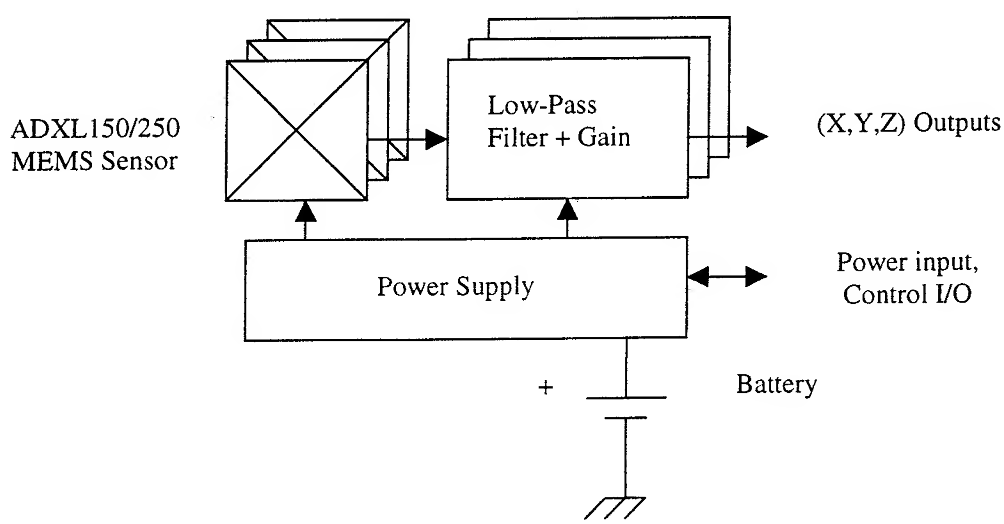


Figure 15

- Plume Experimentation Test-Bed

  In a combustion test oriented laboratory, the need for a hot gas source comes up quite often. For rocket test applications, this must be a high pressure, high temperature, high velocity and reacting source. A Plume Experimentation Test (PET) rocket has been developed for these applications. The thruster shown in Figure 16 is built in igniter, injector, combustion chamber and nozzle sections and modeled after a thruster used at Penn State [9]. It is designed for a chamber pressure of 200 psi and a thrust of 50 lbf. It uses gaseous oxygen as an oxidizer and gaseous hydrogen as a propellant. Plans are underway to design and construct an associated mobile test cell, control and data acquisition system.

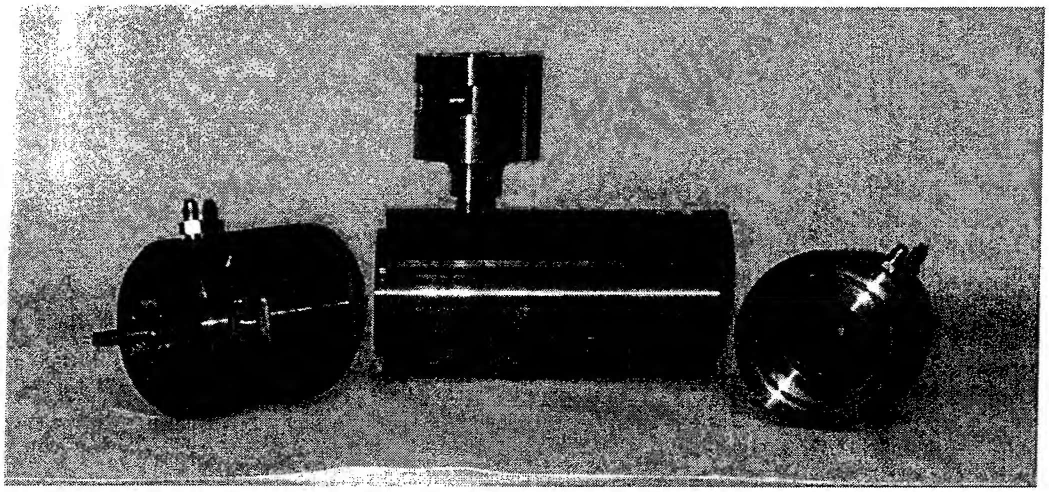


Figure 16

Funding Avenues

Technology Transfer Office
Dual-Use Program
Small Business Innovative Research (SBIR) Program
Small Business Technology Transfer (STTR) Program
Education and University Affairs Office
Resident Research Associateship Program
Summer Faculty Fellowship Program
Graduate Student Researchers Program
EPSCoR Program
Stennis Space Center Director
Center Director's Discretionary Fund (CDDF) Projects

Future Research and Development

Technology is also preparing for accommodating next generation flight vehicle engine test requirements with future research and development projects that may include, in addition to those already discussed, alternate thrust measurement techniques, real time computer cluster signal processing, emission system design upgrades, and atmospheric transmission modeling to name a few.

Acknowledgments

The author wishes to thank her colleagues for their many contributions to the text, presentation and review of this paper including Fernando Figueroa, Harvey Smith, Chuck Thurman, Dave Van Dyke, Jody Woods, and Skip Wright.

Points of Contact

Bill St. Cyr, Ph.D.: NASA Test Technology Branch Chief; 228-688-1134

Skip Wright: Lockheed Martin Technology & Management Support Supervisor; 228-688-7791

NASA Engineers:

- Bob Field, Ph.D.: x3735
- J. Fernando Figueroa, Ph.D.: x2482
- Wanda Solano: x2655
- Peter Sulyma: x1920
- Chuck Thurman: x7680

References

[1] John C. Stennis Space Center History Office, Building 1100, Room 1002, Stennis Space Center, MS 39529-6000, (228) 688-2643. http://www.ssc.nasa.gov/about/history/

[2] G.D. Tejwani, D.B. Van Dyke, F.E. Bircher, D.G. Gardner and D.J. Chenevert, "Emission Spectra of Selected SSME Elements and Materials", NASA Reference Publication 1286, December 1992

[3] NASA's Commercial Technology Program Target of Opportunity Report, Code TA00, Stennis Space Center, MS 39529-6000, (228) 688-1929, http://technology.ssc.nasa.gov

[4] H. S. Smith, "Helmet Mounted Fog/Smoke Camera Penetrating System with Heads-Up Display", Final Report, Lockheed Martin Stennis Operations, Stennis Space Center, MS 39529-6000, March 1999

[5] J. Woods and J. West, "Construction and Utilization of a Beowulf Cluster: A User's Perspective", Preliminary NASA Publication, Lockheed Martin Stennis Operations, Stennis Space Center, MS 39529-6000, Nov 2000.

[6] D. Becker, J. Cedil, C. Halberg and P. Medelius, "The Universal Signal Conditioning Amplifier", Proc. ITC, vol. 30, pp. 626-33, 1994.

[7] F. Figueroa, S. Griffin, L. Roemer, and J. Schmalzel, "A Look into the Future of Data Acquisition", IEEE Instrumentation & Measurement Magazine, December 1999.

[8] Analog Devices, Inc. One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, (617) 329-4700. www.analog.com

[9] M.D. Moser, "Flowfield Characterization in a Uni-element Rocket Chamber", Ph.D. thesis, Pennsylvania State University Graduate School, May 1995.

Acknowledgments

The author wishes to thank her colleagues for their many contributions to the text, presentation and review of this paper including Fernando Figueroa, Harvey Smith, Chuck Thurman, Dave Van Dyke, Jody Woods, and Skip Wright.

Points of Contact

Bill St. Cyr, Ph.D.: NASA Test Technology Branch Chief; 228-688-1134

Skip Wright: Lockheed Martin Technology & Management Support Supervisor; 228-688-7791

NASA Engineers:

- Bob Field, Ph.D.: x3735
- J. Fernando Figueroa, Ph.D.: x2482
- Wanda Solano: x2655
- Peter Sulyma: x1920
- Chuck Thurman: x7680

References

[1] John C. Stennis Space Center History Office, Building 1100, Room 1002, Stennis Space Center, MS 39529-6000, (228) 688-2643. http://www.ssc.nasa.gov/about/history/

[2] G.D. Tejwani, D.B. Van Dyke, F.E. Bircher, D.G. Gardner and D.J. Chenevert, "Emission Spectra of Selected SSME Elements and Materials", NASA Reference Publication 1286, December 1992

[3] NASA's Commercial Technology Program Target of Opportunity Report, Code TA00, Stennis Space Center, MS 39529-6000, (228) 688-1929, http://technology.ssc.nasa.gov

[4] H. S. Smith, "Helmet Mounted Fog/Smoke Camera Penetrating System with Heads-Up Display", Final Report, Lockheed Martin Stennis Operations, Stennis Space Center, MS 39529-6000, March 1999

[5] J. Woods and J. West, "Construction and Utilization of a Beowulf Cluster: A User's Perspective", Preliminary NASA Publication, Lockheed Martin Stennis Operations, Stennis Space Center, MS 39529-6000, Nov 2000.

[6] D. Becker, J. Cedil, C. Halberg and P. Medelius, "The Universal Signal Conditioning Amplifier", Proc. ITC, vol. 30, pp. 626-33, 1994.

[7] F. Figueroa, S. Griffin, L. Roemer, and J. Schmalzel, "A Look into the Future of Data Acquisition", IEEE Instrumentation & Measurement Magazine, December 1999.

[8] Analog Devices, Inc. One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, (617) 329-4700. www.analog.com

[9] M.D. Moser, "Flowfield Characterization in a Uni-element Rocket Chamber", Ph.D. thesis, Pennsylvania State University Graduate School, May 1995.